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# MEASUREMENT OF LOW FREQUENCY VIBRATIONS IN BIG HELICOPTERS AND THEIR TRANSMISSION TO THE PILOT

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Analyses are presented of the vibrations recorded at the seat level and on the sternum and cranium of the pilot. Sources are identified as (1) very low frequency vibrations due to atmospheric turbulence occurring at low altitudes and in clouds; and (2) vibration caused by mechanical factors in the main rotor and the anti-torque rotor. The frequencies transmitted to the cockpit are multiples of the number of blades of the frequency of rotor rotation. The helicopter used produced mechanical vibrations of 20 Hz and above, caused principally by the main rotor. The damping function of the body upon increased frequencies is demonstrated, with the resonant frequencies of the human body found in the 4 to 6 Hz region in seated subjects. Between 25 and 30 Hz, an over-acceleration of the head in relation to the shoulder was observed. Above 6 Hz, a damping effect occurs especially in the longitudinal axis. The problem of damping very low frequencies (2 to 6 Hz) is considered the most difficult to solve; deflections of several units of 10 cm would be necessary to reduce the resonance of the seat-pilot system below these figures.

The importance of helicopter vibrations has been pointed out since the appearance of the first models. In 1936 the pilot Maurice Claisse noted the disagreeable character of the vibrations that reverberated from the whole machine, and after one hour of flight he hurried back to the hangar to nurse his aches. This phrase, quoted by Vice Admiral Jubelin, is still true. Mechanical progress has been made and the vibrations are less. However, with the generalized use of helicopters and the lengthening of flights, the problem of the repercussion of vibrations on the pilots is pinpointed. /345*

According to clinical studies of Missenard and Terneau, and of Pellet in 1957, of Fabre and Greber in 1959, Montagard, Saìs and Guiot in 1961, and particularly according to Sliosberg's thesis in 1962, the relationship between vertebral pain, lumbosciaticas and helicopter piloting is clearly established. Sliosberg's investigation relates to 128 pilots. Among these, 112, i.e., 87.5 percent, had pain; generally the pains begin with the 300th hour of flying time. However, pilots with pathological condition of the spinal column began to suffer earlier, after 50 or 100 hours of flying time. An extended mission, or a difficult one, evokes pain whose duration is a function of the pattern of the flights. Average figures that are cited in the study as threshold of appearance of difficulties are 4 to 5 hours per day, 40 to 50 hours per month. In the second part of this discussion we will analyze the pathological symptoms observed by the pilots.

*Numbers given in margin indicate pagination in original foreign text.

In the course of tests of the Sud Aviation heavy helicopter Super Frelon 3210, we were struck by the statements of pilots who boasted of the comfort of the machine and particularly stressed the low level of vibration. We recorded vibrations on the three axes at seat level and on the pilot at the level of the sternum and the crest of the skull. We then attempted to analyze the phenomenon and particularly to establish the correlation between the recordings and the subjective feelings of the pilots.

We used six identical measuring tracks, recorded simultaneously. 1st configuration:

- seat vibrations, axes x, y, z;

- sternum vibrations, axes x, y, z.

2nd configuration:

- seat vibrations, axes x, y, z;

- crest of skull vibrations, axes x, y, z.

/346

The recordings were made in the course of various phases of flight: taxiing, takeoff, forward motion, flight at different altitudes and different speeds, turning to the right and left with more or less significant load factor, backward travel, and landing.

The composition of each track was as follows:

Pickup: accelerometer with variation of mutual induction J222 - $\pm 2$ g 5. Ateliers de construction Bagneux.

Supply: supply unit on 28 V. 333 W. Carrier current generator unit 313 W, 1000 Hz frequency. Sexta.

Amplifier: amplifier and demodulator unit. 304 W. Sexta.

The output of the measurement system which was of quite conventional design was recorded in frequency modulation on an onboard magnetic recorder, Tolana A 4022.

In addition to the 6 tracks of vibrations recorded in parallel, the strip received data on the sound track and reference voice signals aided the analysis.

This latter was achieved via a Tolana MN 1400 reader and W 0713 demodulators. The analog representation was done on photographic recorder with direct writing. A 0300 ACB and frequency analysis was made on the B. F. Bruel and Kjaer spectrum recorder.

Since it was possible to modify the reading speed with reference to recording speed, we were able to achieve frequency analysis very much below Bruel and Kjaer's theoretical possibilities: 3 Hz instead of 12.

Below 3 Hz the analyses were carried out manually, based on the analog representation.

The recorded vibrations have two distinct origins.

1. Very low frequency vibrations due to atmospheric turbulence which appear particularly at low altitude and in clouds. These vibrations are composed of responses of the cellule to excitations of aerodynamic origin and to the actions of the pilot through the servo controls.

2. Vibrations of mechanical origin deriving from the main rotor, the anti-torque rotor, the engines, transmission systems, etc. The highest levels correspond to a frequency that depends upon the rpm of the rotor and the number of blades that characterize it (nota bene). In the case of the SA3210 the rotor has 6 blades and turns at 202 rpm. Hence the frequency is 20.2 Hz. The anti-torque rotor turns 4.7 times faster, but it has only 5 blades instead of 6. The transmitted frequency will thus be 79.4 Hz.

This frequency has much less important effects because it is filtered by the seat and probably by the lower parts of the body.

As a matter of fact the recordings made on the pilot show practically no response to this excitation.

/347

The analog representation of the vibrations on the z axis in the course of a phase of stabilized flight (fig. 1) shows the evolution of vibrations at the level of the seat, the sternum and the cranium of the pilot. The most apparent frequency, that which strikes the eye, is the 20.2 Hz. This frequency is modulated in very low frequency by 0.7 or 1 Hz as a function of the flight phase and the intensity of the turbulence. The 0.7 Hz frequency appears very often in our recordings, corresponding to the response of the servo control. There are then found low frequencies in the range 3 to 30 Hz. The 20 Hz recording appears very clearly, and on the seat there are higher frequency vibrations, particularly 40 Hz which is harmonic 2, and higher frequencies that do not appear in the recordings taken at the pilot level.

Figure 2 shows the spectrum of frequency on the z axis at seat level and the two pilot reference points (sternum and crest of the skull) in horizontal flight at 260 km/hour. It will be observed that at low frequency there is no damping, whereas from 10 to 15 Hz for the sternum and 20 Hz for the head a more and more significant damping is evident.

Figure 3, turning the right shows the same picture.

Figure 4 and 5 show the x axes in the same flight configurations. The preponderance of 20 Hz and a fairly significant very low frequency level is to be noted. The spectrum of figure 5 is interesting because in frequencies of 4 to 6 Hz the acceleration at skull level is greater than that of the seat. In contrast, there is much damping at the sternum. The y axes shown in figures 6 and 7 present the characteristics of higher accelerations at the sternum than at the skull. This can be explained by the fact that the seat back is tilted at an angle with reference to the vertical and that the pilot is attached at the

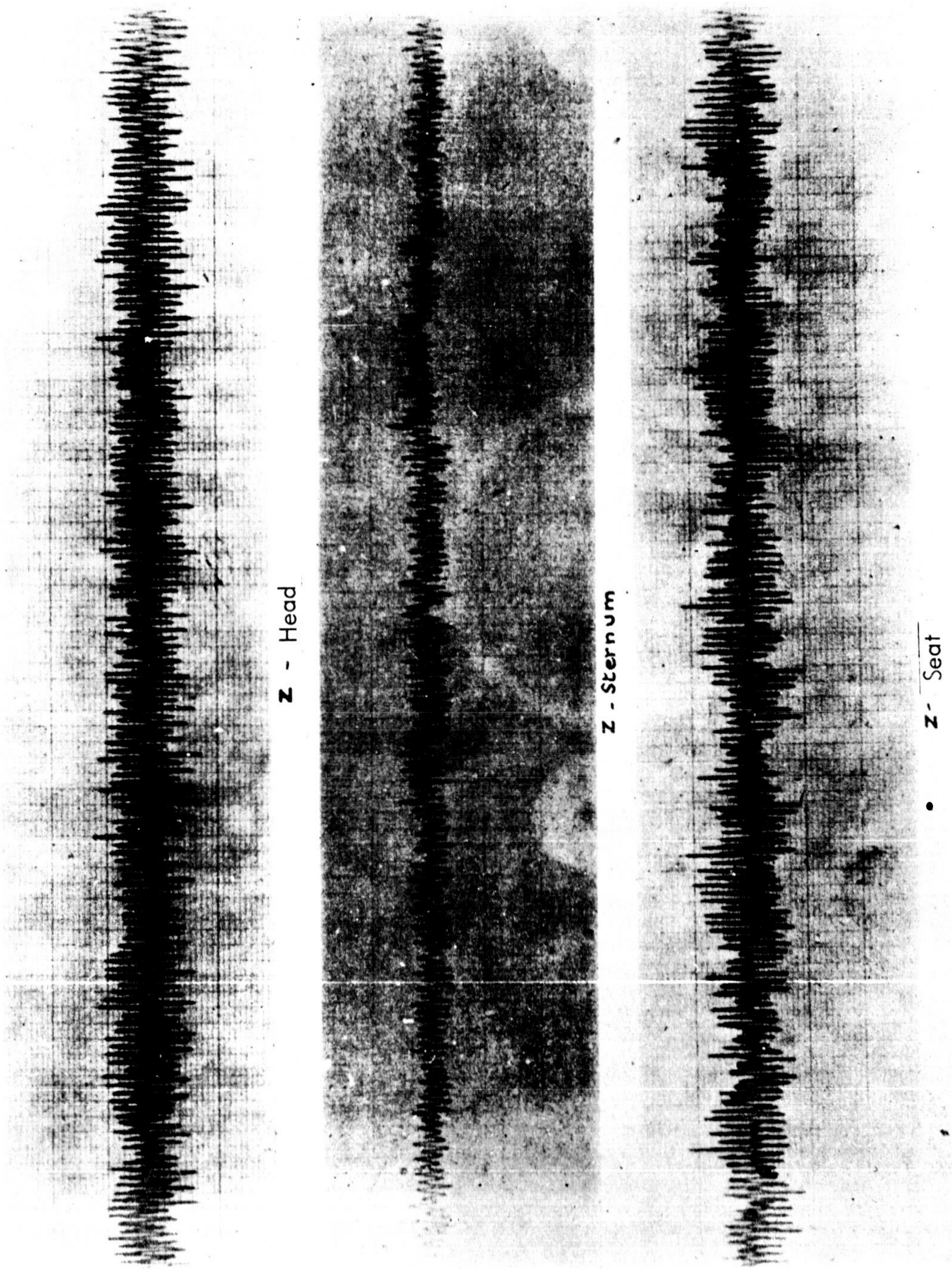


Figure 1

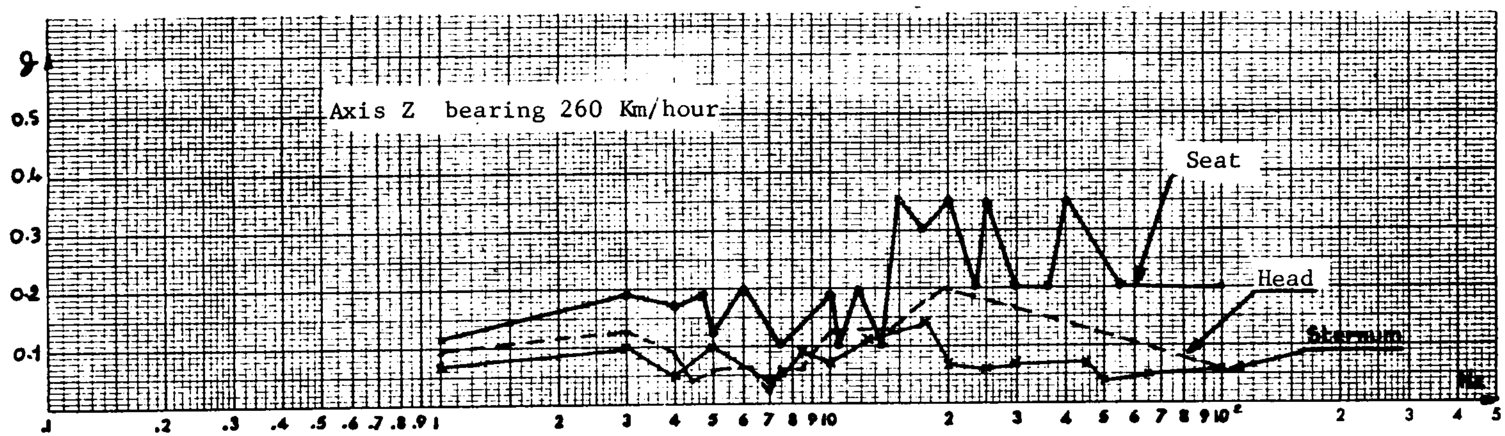


Figure 2

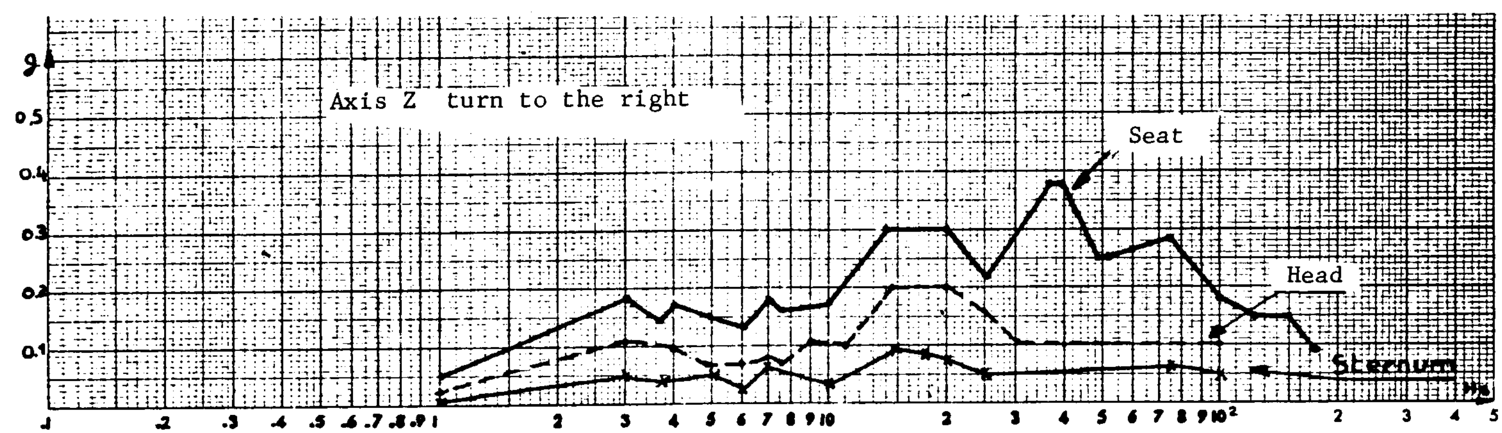


Figure 3

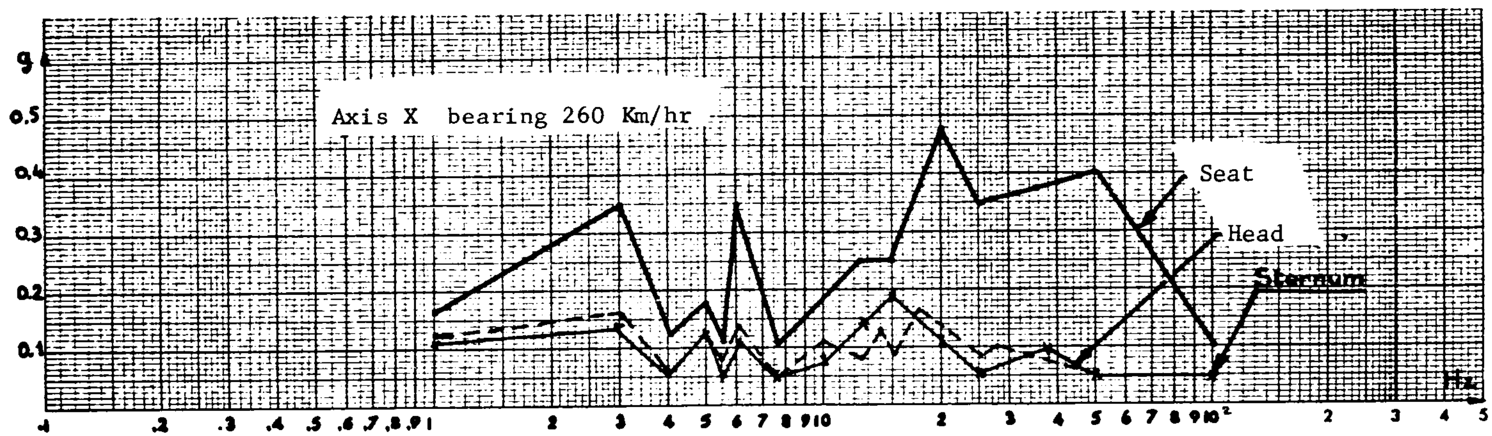


Figure 4

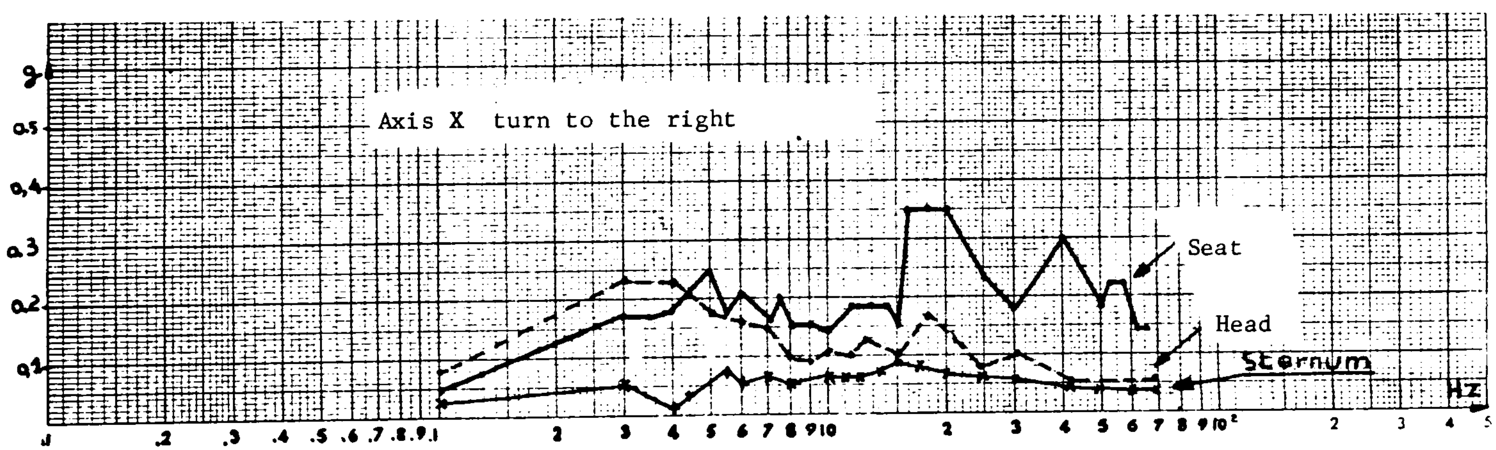


Figure 5

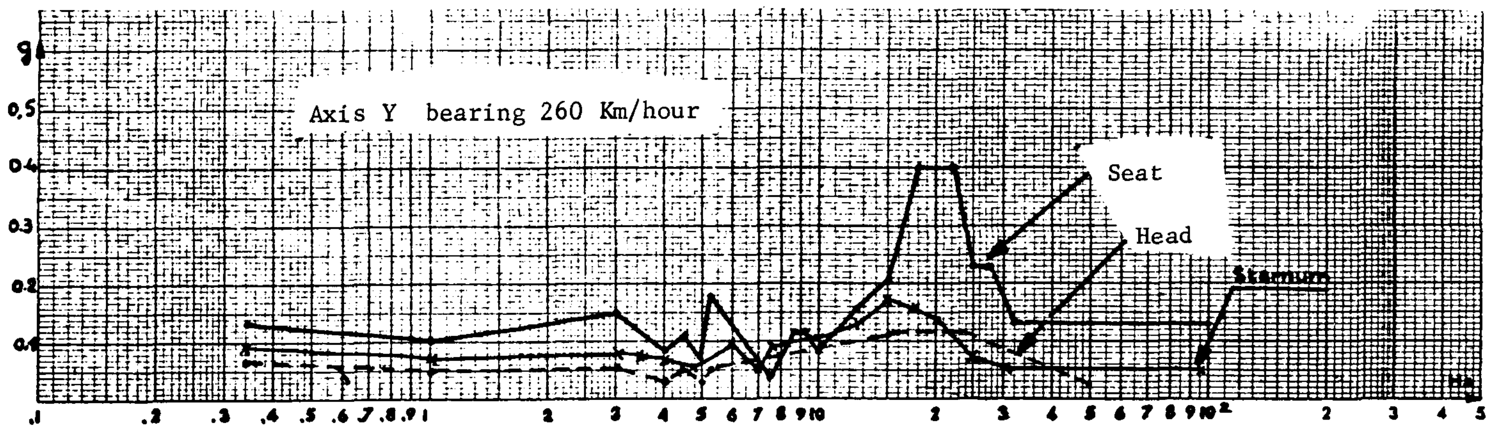


Figure 6

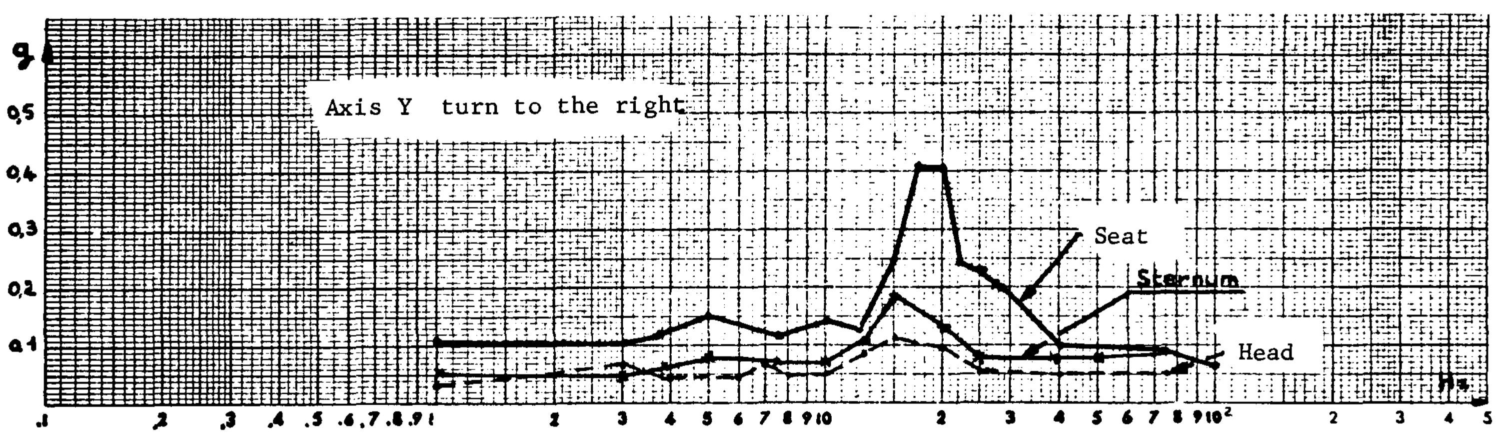


Figure 7

shoulders by the harness straps. Moreover on this axis the cushions damp much less than on the x axis.

The very low frequencies of aerodynamic origin are those that entail maximum discomfort. Depending upon the axis, the position and the degree of muscular contraction, there is observed a relative increase of vibration levels on the pilot between 4 and 7 Hz. Moreover these frequencies are very difficult to filter. In contrast, the vibrations of mechanical origin above 15 Hz are well damped by the seat and by the pilot's body. This phenomenon explains the sensation of relative comfort described by the pilots as they compared the Super Frelon with other craft.

The frequency spectrum of Alouette II shows two peaks at 6 and 18 Hz, that of Sikorsky S58 at 3.7 and 15 Hz. The 20 Hz frequencies and above which characterize the Super Frelon are less bothersome for the pilot in proportion to their separation from the resonances of the human body.

What may be the consequences for the pilot? The Sliosberg study, the papers by Dieckman, Goldman and Von Gierke, and the experiments of Goerman, Clark, White, Hornick and Parks allow us to make a prediction. On short range, that is to say, during flight and particularly at the end of a 3-to-4 hour mission there is noted essentially phenomena of diffuse fatigue with a more or less pronounced drop in performance.

Recovery is more or less rapid, depending upon the degree of fatigue and of course upon the rest available to the crew.

/348

This fact is not peculiar to the helicopter pilot. Many airplane pilots show similar symptoms, particularly after high speed, low altitude missions, in the course of which we have recorded vibration curves that are comparable but at a much higher level.

In the long range, helicopter pilots suffer back pain in 87.5% of the cases after 1 or 2 years of operation.

Of the 128 pilots studied by Sliosberg, 35 complained of neck pain, 54 of back pain, and 96, i.e. 75 percent, of lower back pain, 11 of them with distinct sciatic radiation. The clinical signs are generally fairly clear and go from simple limitation of movements of the trunk to perivertebral muscular contraction and the classic symptoms of sciatica. Radiological examination reveals an abnormal frequency of lumbar scolioses, and Montagard points out discrete signs of arthrosis also.

The evolution is a function of the rhythmic pattern of flights. The threshold of appearance of pain is at more than 4 to 5 hours per day, more than 40 to 50 hours per month.

Extended rest, periods of vacation, change of craft and particularly periods on airplanes bring about a soothing or a disappearance of the pain. With resumption of concentrated helicopter flights there will be a corresponding return of pain phenomena.

All the subjects with a "back history" either of traumatic origin (crash, parachute jumps) or following a very great number of flying hours in airplanes, or those with congenital anomalies, are predisposed. In contrast, pilots who have systematically engaged in athletics are better protected. A good abdominal and perivertebral musculature increases resistance to vibration and retards the appearance of pain phenomena.

As Wisner showed, the perivertebral muscles act as dampers and the important work to which they are exposed will involve pain.

With fatigue their damping action diminishes and even disappears, the vibrations then acting directly on the intervertebral disks-vertebrae assembly. Keegan showed that the seated position involves an increase of pressure at the level of the anterior portion of the disk. The force exerted by the vibrations will increase this excess pressure and drive the nucleus pulposus toward the back, i.e., toward the capsuloligamentary sheath and the neural roots. A forward-bent position naturally aggravates the phenomenon. It is often combined in takeoff and landing phases with a flexion to the left to reach the low stop of the cyclic pitch. We have observed furthermore that these flight phases are accompanied by a high level of low frequency vibrations.

In conclusion, the Super Frelon SA 3210 presents a spectrum in which there are combined two sources of vibration of different origin. The very low frequencies of aerodynamic origin are in the range of resonances of the human body. Their damping is very difficult to achieve. There would have to be deflections of several decades of centimeters.

/349

20 Hz frequencies and above, of mechanical origin, emanate from the main rotor, the antitorque rotor and the engine. Since these frequencies are above human body resonances, they are less well perceived by the pilot.

Their effects are much less apparent, particularly in back pain. The position of the pilot on his seat is more favorable because it is inclined slightly backward. The control of the cylic pitch is effected in such a way that the pilot is not required to lean forward and to the left to manage it.

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# ERRATA

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